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DEPARTMENT OF METEOROLOGY

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TECHNICAL REPORT

Some Meteorological Conditions Associated with the Rainfall Resulting in the Kansas City Flood of July 13, 1951

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ABSTRACT

This paper is concerned with some of the meteorological conditions associated with the intensive rainfall over Kansas which resulted in one of the major floods in the Middle West on July 13, 1951. The major damages were in the industrial areas of Kansas City, Kansas, and Kansas City, Missouri.

The precipitation had a diurnal maximum near 3 A.M. local time and minimum during late afternoons. From July 9th to the 13th there was a stationary front along the border of Kansas and Oklahoma. The circulation in the lower layers was such that there was a component of wind up the frontal slope. This northward component of the wind also had a diurnal variation which agreed closely with the diurnal variation in precipitation. There was convergence at 10,000 ft. over the precipitation area most of the time throughout the period. The slight diurnal variation in the difference between the temperature and dewpoint in the lower layer of air being lifted was also a factor which added to the diurnal variation in precipitation.

1. INTRODUCTION

A major flood developed in the Central United States July 13, 1951. The greatest damages were in the industrial areas of Kansas City, Kansas and Kansas City, Missouri. According to Alexander [1] , preliminary estimates indicated one billion dollars of physical damage and an equal amount in losses due to interruption of business and production. The loss of 17 lives may be attributed directly to the flood.

Most of the rainfall contributing to the flood occurred from the 9th to the 13th of July inclusive. It appears from the U. S. Weather Bureau data that the larger amounts of precipitation during this period were more or less concentrated over the northern and eastern parts of Kansas. During this five-day period some official Weather Bureau rain gages measured over 15 inches while some unofficial gages reported more than 17 inches. The isohyetal map in fig. 1, taken from [2] , shows the excessive rainfall pattern for the storm. With such heavy rainfall day after day, the soil soon became completely saturated, resulting in heavy runoff into the streams which finally overflowed their banks.

According to Handeby [3] , the runoff value approached very close to 100 per cent by the end of the period. Runoff values were large because the soil at the beginning of the period was still quite wet from the excessive precipitation in June. The isohyetal map in fig. 2, taken from [2] , shows the rainfall patterns for June 1951. According to the U. S. Weather Bureau publication of climatological data [4] , the average rainfall over Kansas for June 1951 was 9.55 inches. This was 5.58 inches above normal.

A very interesting feature, which is not obvious from the ordinary analysis of the surface weather maps of 0030 GMT and 1230 GMT [figs. 6 through 11] at the end of this paper, is the diurnal variation of precipitation. In fig. 3 the number of stations reporting rainfall in Kansas was plotted for each hour during the five-day period. Fig. 4 shows the total amount of rainfall each hour during the period. Fig. 5 shows the average rainfall per reporting station in Kansas for each hour during the period. These three graphs were prepared from the Climatological Data for Kansas [5] to establish firmly the fact that there was a diurnal variation in precipitation during the storm period. It is obvious that one should be more concerned with quantitative considerations of diurnal variations while investigating a flood problem, but, as far as the scope of this paper is concerned, it was felt that these graphs would be sufficient.

2. SURFACE ANALYSIS

The series of surface weather maps, figs. 6-11, is for the period July 10-13, 1951. A cold front moved over the northern plains to Kansas on the 8th with no appreciable rainfall being reported. As the front moved southward it decelerated, becoming stationary in southern Kansas and northern Oklahoma by the afternoon of the 9th. This is shown in fig. 6. The wedge of cold air behind the front, even though relatively thin, was sufficient to produce clouds, scattered showers and thunderstorms in the warm air moving northward over the frontal surface. This condition prevailed for several days. During this time the front remained practically stationary and there was a diurnal

variation in precipitation. It was not determined in this investigation whether or not there was a widening of the frontal rain belt during the night as was suggested by Dexter [6] . Finally the front began to move slowly southward, as shown in fig. 11, with diminishing rain and thunderstorm activity especially over the area we are concerned with. The times of the surface weather maps do not correspond to the times at which maxima and minima of the diurnal variation in precipitation occurred. Therefore the greatest degree of diurnal variation could not be detected from these surface weather maps alone.

3. CONDITIONS ALOFT AND DIURNAL VARIATION IN PRECIPITATION

It was pointed out by Carr [7] that the characteristic flow pattern of the middle troposphere air over the western part of North America during June and the early part of July, consisted of a north-south ridge of high pressure over the Gulf of Alaska and a trough of low pressure extending from the Dakotas southwestward to Nevada and Utah. Once this trough is formed it usually lasts for several days. This condition was predominant during the period under consideration, as is shown on the 700-mb charts, figs. 12-14. However, during the latter part of the period the trough disappeared (see fig. 17). The persistence of the ridge in the Alaskan Gulf is considered to be a very important feature in the study of such troughs. The ridge might be thought of as a parent to the trough because once the ridge is formed, a trough will develop downstream. This fact might be explained, in part, by a consideration of Rossby's idea of constant vorticity trajectories. Alternatively, Carr [7] describes Wobus'

explanation of this dynamic factor (unpublished paper not available to writer) in the following manner. "Assuming that air parcels approaching the ridge from the southwest have a fairly high speed (as is often observed) they will not only fail to curve with the contours but will move across them toward lower contour heights, resulting in acceleration. Then, if the geostrophic wind as indicated by the contour gradient to the east of the ridge is less than the actual wind speed (as is frequently observed), the air parcels must curve to the right. In doing so they move toward higher contours, decelerate, and later recurve to the left, the trajectory taking the form of a trough. ..... His theory assumes that the contour field tends eventually to become adjusted to the wind flow, requiring for the formation of the trough that the atmosphere undergo net horizontal mass divergence in the area of trough formation."

In this investigation, there was found in the troposphere, especially at the 700-mb surface, a persistent ridge in extreme western Canada and a trough oriented mainly northeast-southwest from the Dakotas to Nevada and Utah. Rain, mostly in the form of showers, was occuring north of the stationary front. Later in the period, the ridge of high pressure weakened and gradually moved eastward. The trough then disappeared. By this time, the stationary front through southern Kansas and northern Oklahoma began to move southward. Then rain ceased over Kansas.

This investigation included wind field analyses at one level only because of time limitations. It was decided to focus attention on

the 10,000-ft level. This level was chosen for two reasons. First, it was desirable to select a level above the friction layer so as to minimize the number of singular points in the wind field, and which will be more or less representative of the flow in the lower troposphere. Secondly, it was desirable to consider a surface below the level of nondivergence so that the divergence computed on this surface would be representative of the lower layer.

Wind field analyses were made for the 10,000-ft level twice daily at 0300 GMT and 1500 GMT during the period. All available wind data were used in preparing the isogon-isovel analyses. Streamlines were drawn on these isogon-isovel maps. Figs. 15-16 show the 10,000-ft streamlines and isovels at 0300 GMT and 1500 GMT on the 12th of July 1951. The characteristic flow patterns on these two maps are considered to be very nearly representative for this level throughout the period.

Fields of the horizontal velocity divergence were computed from the isogon-isovel maps by the use of the Graham Computer [8]. Some of these are shown in figs. 18-21. It can be seen from these maps that most of the state of Kansas was in a zone of convergence at 10,000 feet throughout the period of large diurnal variation in precipitation. It should be noted, however, that horizontal convergence for only one level is shown. To obtain a representative value of the convergence in the lower layer it is obvious that one must consider more than just one level.

The diurnal variation in precipitation agrees very closely with the variation of the northward component of the wind in the

warm air which is being lifted along the frontal surface. In fig. 22 graphs (a)-(m) are the profiles of the northward component of the wind at Oklahoma City, Oklahoma. Whenever wind data from Oklahoma City were missing, wind data at Tulsa, Oklahoma were substituted. These profiles are for every six hours from 0900 GMT on July 10th to 0300 GMT on the 13th.

These profiles clearly show that the strongest northward component of the wind throughout the period occurred at 0900 GMT at a height of 2,000 to 3,000 feet above the station. The times of this strong northward component of wind agree very closely with the times at which there were diurnal maxima of precipitation. To obtain a relative measurement of the mass of air moving northward, the areas of the profiles under 8,000 feet were measured in percentage of the area at 0300 local time, July 10, 1951. These percentage measurements are shown in table 1.

If it is assumed that there is no time variation of the air density at any given level between the surface and 8,000 feet, it can easily be seen from the profiles and table 1 that the observed relative transport of air northward was greater at 0900 GMT than at any of the other observation times. This maximum mass transport also agrees closely with the times of diurnal maxima in precipitation. After studying the profiles and table 1, one may suspect that the maximum northward component of the wind and the maximum percentage area of the profile occurred a short time before 0900 GMT. If one correlates the movement of mass of air up the frontal surface with the amount of rainfall, one must consider a time lag, the time required

for the precipitation to reach the ground and be recorded. A time lag of one to two hours seems reasonable.

TABLE 1

PERCENTAGE AREAS OF THE WIND PROFILES IN FIG. 22

Fig. 22	Area	CST	
(a)	100	0300	7/10/51
(b)	65	0900	
(c)	59	1500	
(d)	(missing)		
(e)	88	0300	7/11/51
(f)	50	0900	
(g)	45	1500	
(h)	60	2100	
(i)	69	0300	7/12/51
(j)	41	0900	
(k)	52	1500	
(m)	51	2100	

If such a time lag is considered in this investigation and the maximum mass of air moved up the frontal surface a short time before 0900 GMT, the agreement in the times of maximum precipitation and the maximum air movement is improved.

Another matter for consideration is the amount of lifting necessary to produce condensation. This was considered by investigating the radiosonde observations at Oklahoma City during the period.

The average amount of lifting necessary to produce condensation was computed at 0300 GMT and 1500 GMT on the 11th and 12th of July 1951. In the computation of these averages, the amount of lifting required was determined from a Stuve diagram for selected points on the sounding, the selected points being all significant points from the surface to 850 mb inclusive. In most cases only three points were used. These averages are shown in table 2.

TABLE 2

AVERAGE AMOUNT OF LIFTING NECESSARY TO PRODUCE CONDENSATION IN THE LAYER OF AIR BETWEEN THE SURFACE AND 850 MB AT OKLAHOMA CITY

Date	Time (GMT)	Amount of Lifting (ft)
July 11, 1951	0300	2300
July 11, 1951	1500	2600
July 12, 1951	0300	2400
July 12, 1951	1500	3200

The soundings at 0300 GMT (9 P.M. local time) indicate that surface cooling had already begun. Soundings at 1500 GMT (9 A.M. local time) show a dry adiabatic lapse rate in a very thin layer near the earth's surface.

In each of the above cases there is a marked increase of lifting necessary to produce condensation of the lower layer of air, from the evening to the morning soundings. It is quite possible that if soundings were available for 0900 GMT and 2100 GMT they would show a greater difference, because soundings at those times would show a greater amount of radiational cooling and daytime heating respectively.

Means [9] suggests that the advection of warm air in the lower layers is an important factor in the development of night-time thunderstorms in Mid-western U. S. In the investigation of this situation, it was found that frontal lifting seemed to be a much more important factor.

4. CONCLUSION

In this investigation it was found that there was a marked increase in the transport of air up the frontal surface from 2100 to 0900 GMT with a probable maximum shortly before 0900 GMT. Also, there was a decrease in the transport of air up the frontal surface from 0900 to 2100 GMT. Since the amount of lifting necessary to produce condensation is a function of the difference between the temperature and dewpoint, the diurnal variation in this difference, however small, produced a noticeable effect. The layer of air below 850 mb at 0300 GMT required less lifting to produce condensation than it did at 1500 GMT. The combination of these factors, and possibly others, resulted in an increase in precipitation during the night and a decrease during the day.

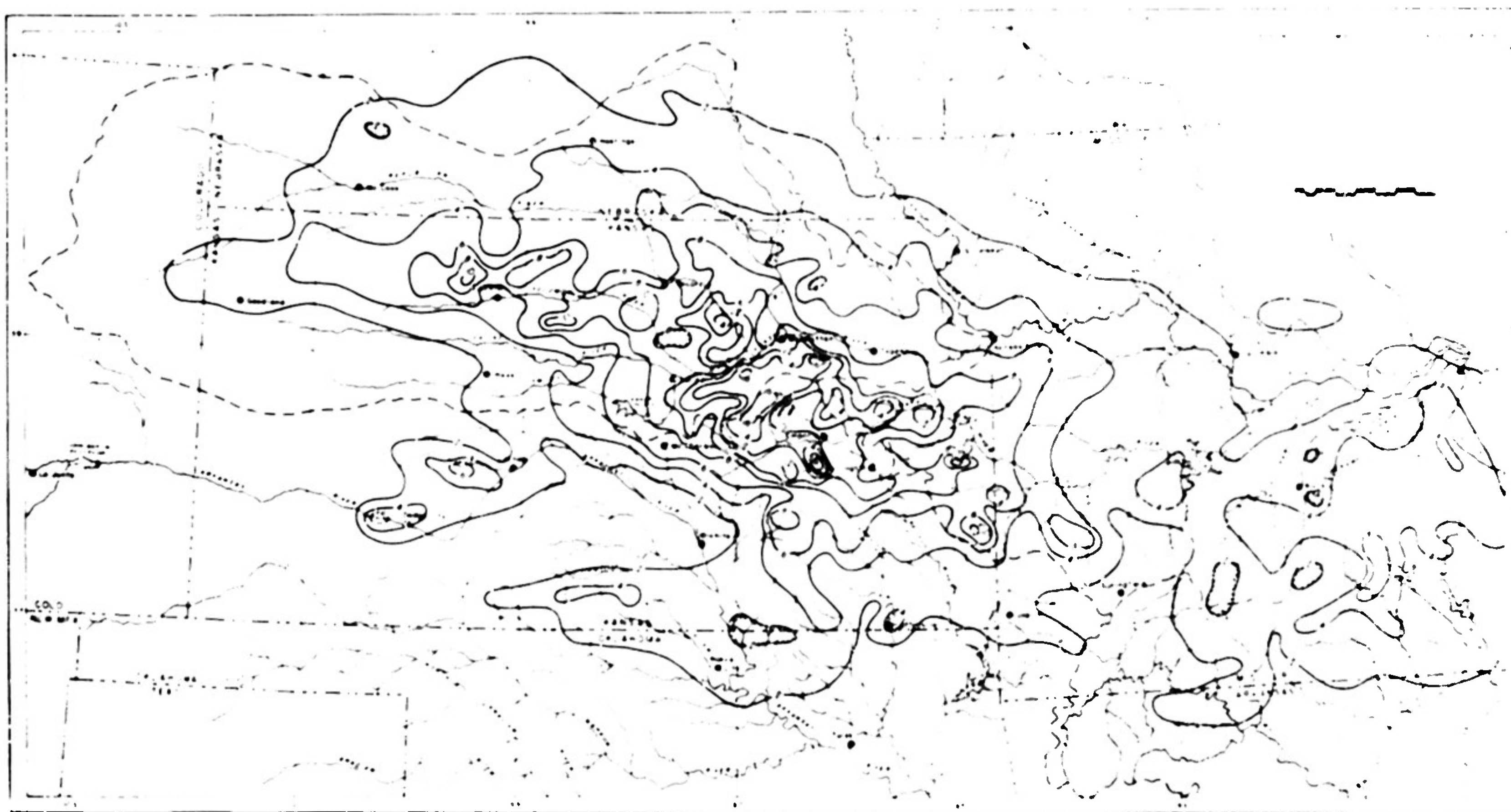


FIG. 1. Total precipitation for storm of July 9-13, 1951

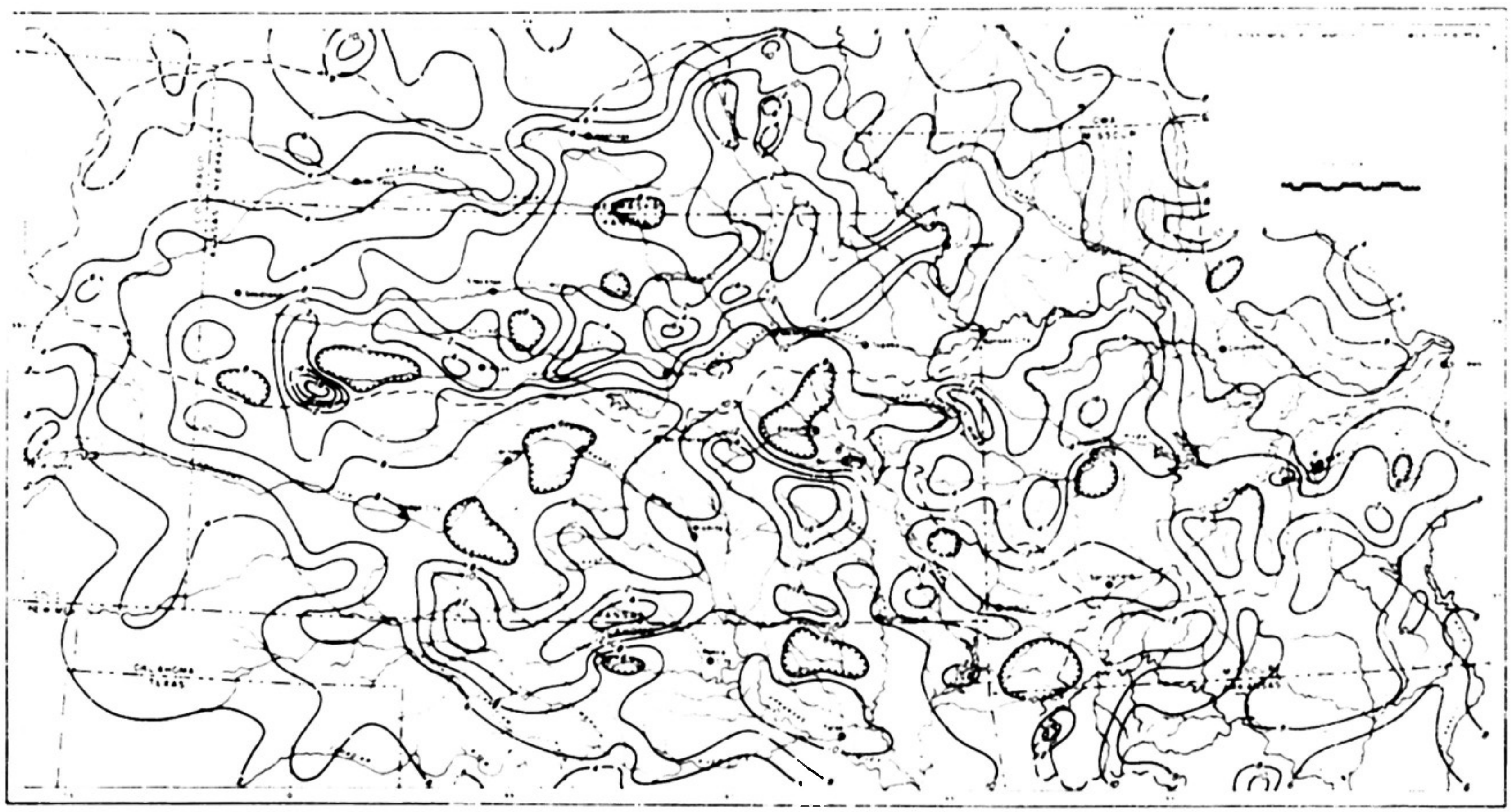


FIG. 2. Total precipitation for June 1951

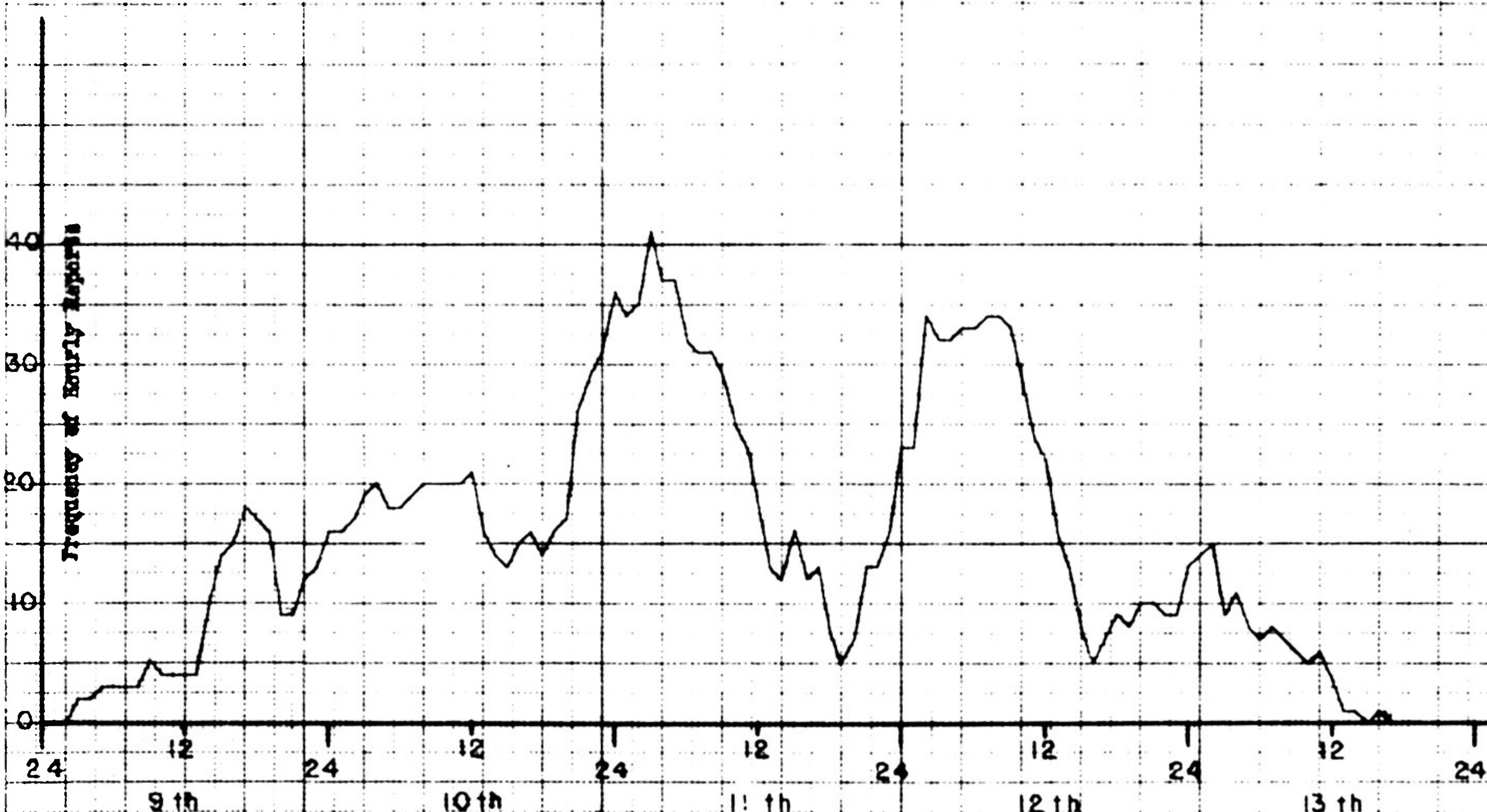


Fig. 3. Hourly Frequency of Rainfall Reports in Kansas on July 9-13, 1951

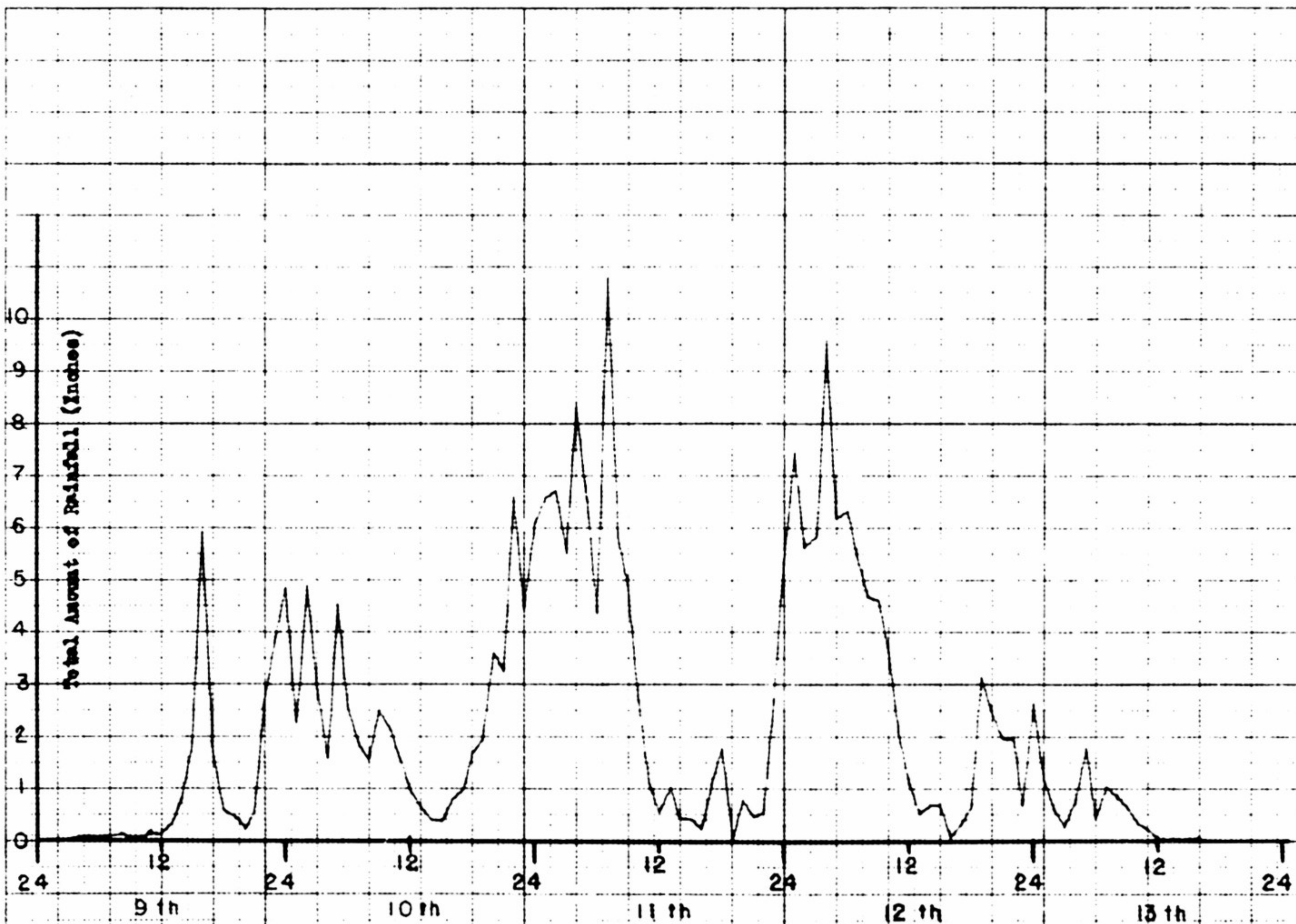


Fig. 4. Total Amount of Hourly Precipitation in Kansas on July 9-13, 1951

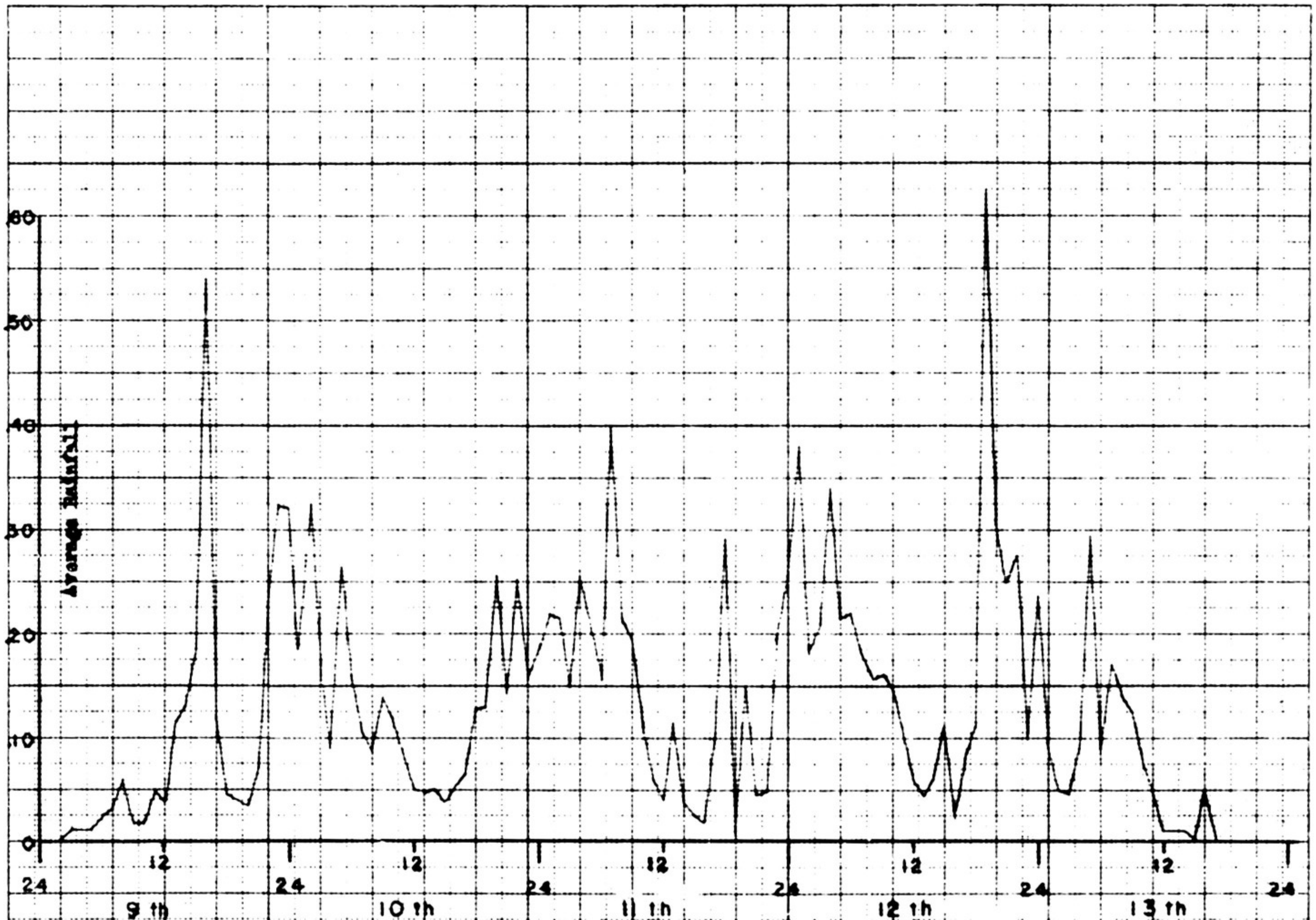


Fig. 5. Average Hourly Rainfall per Reporting Station in Kansas on July 9-13, 1951

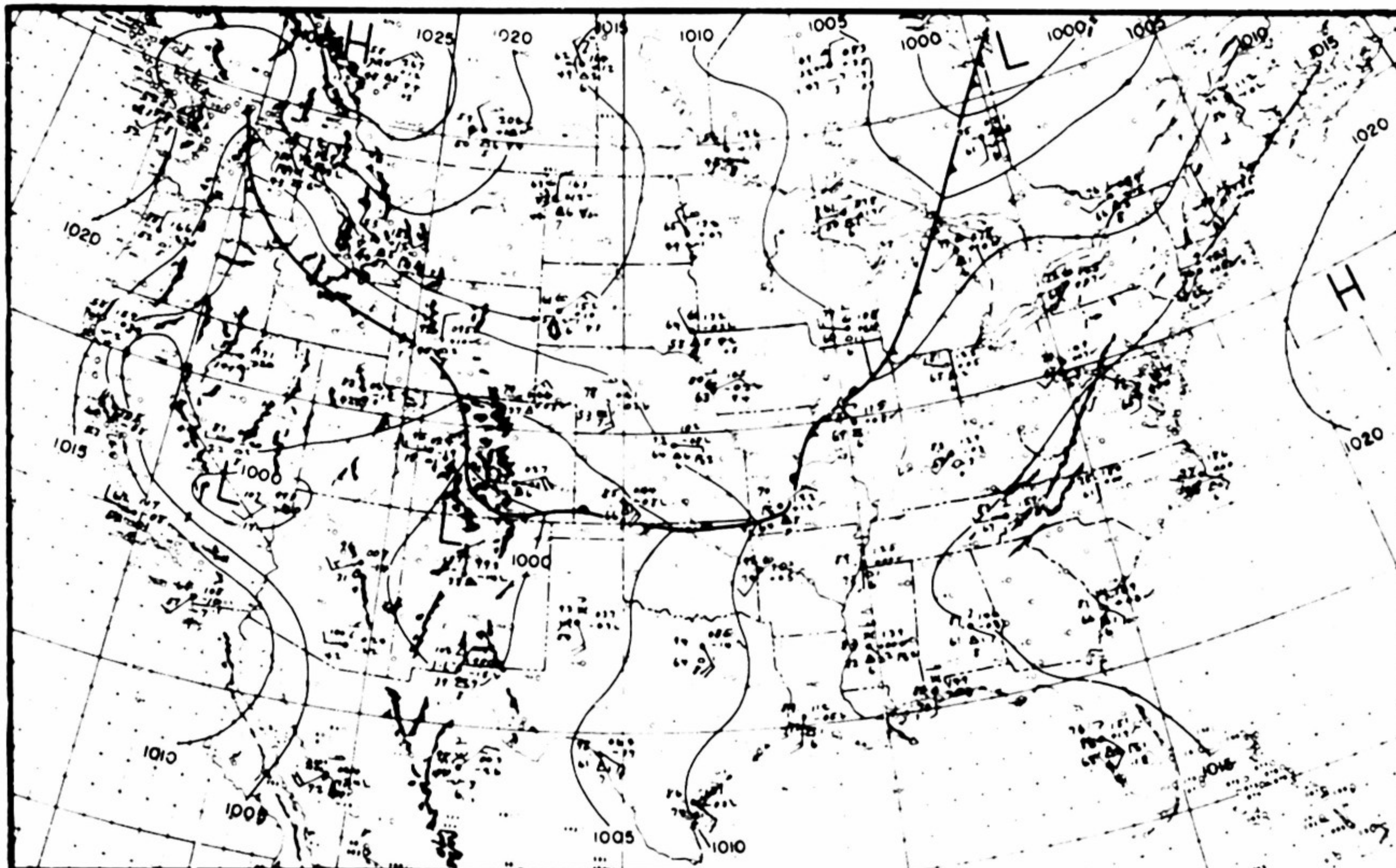


FIG. 6. SURFACE MAP JULY 10, 1951, 0030 GMT

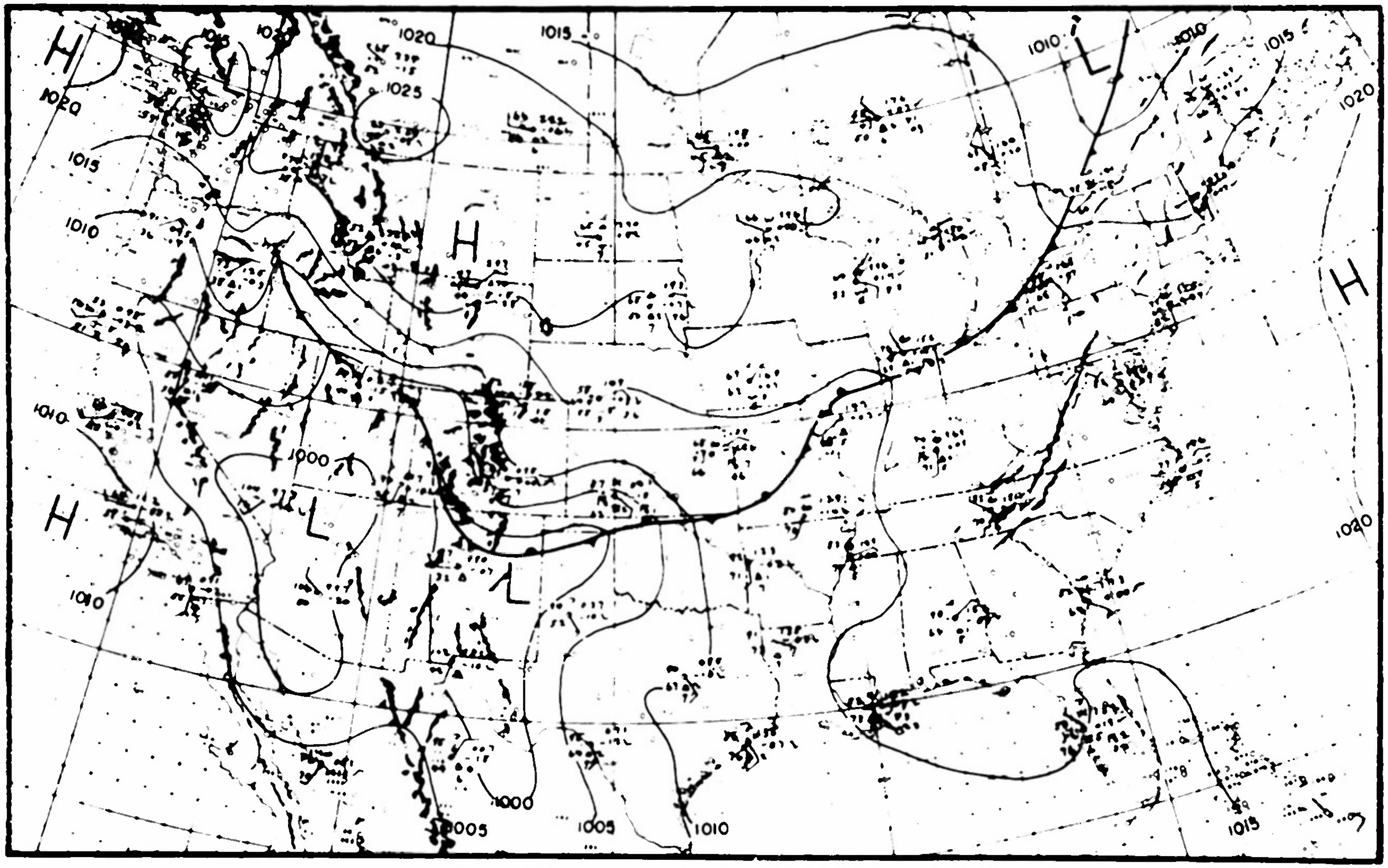


FIG. 7. SURFACE MAP JULY 11, 1951, 0030 GMT

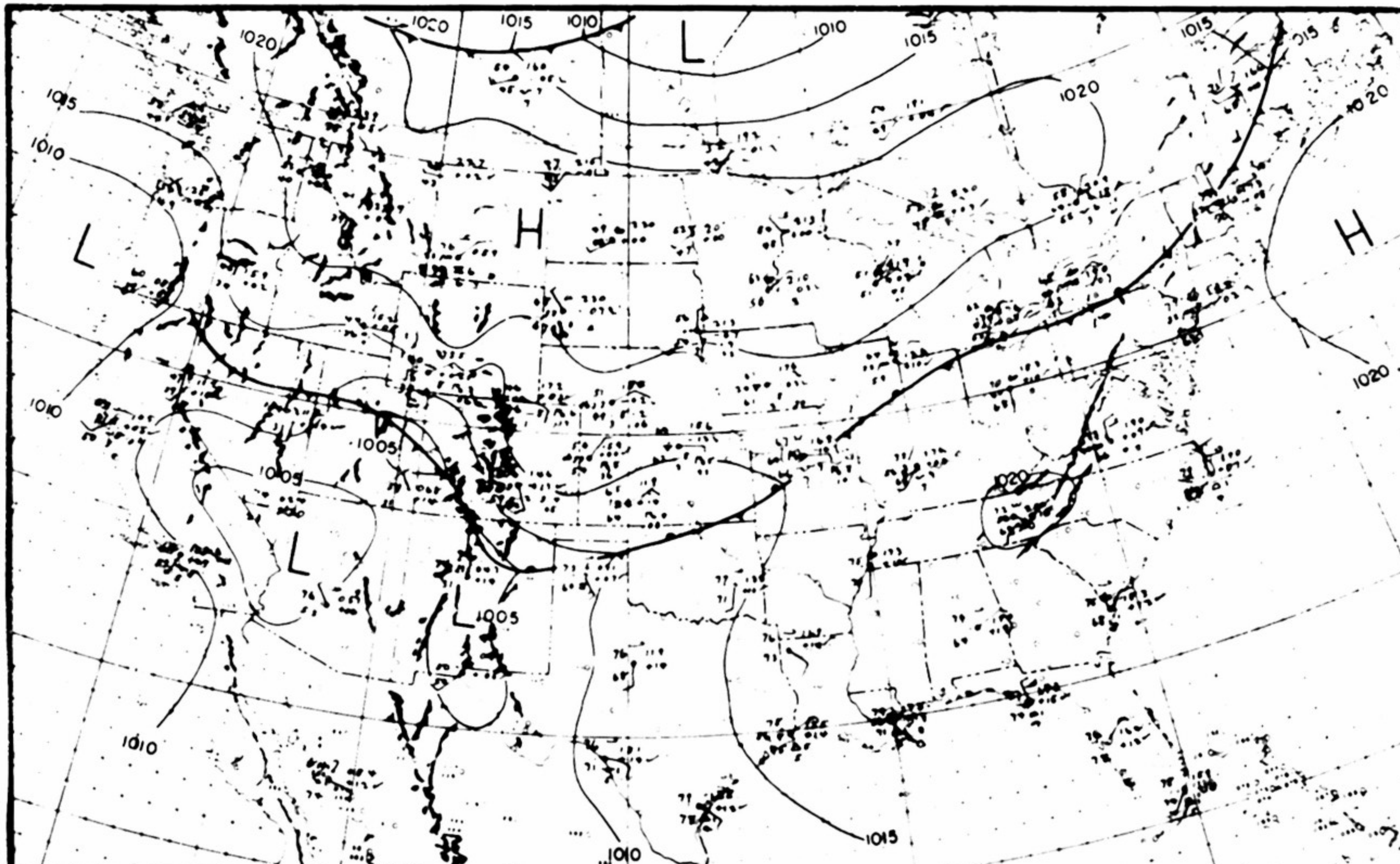


FIG. 8. SURFACE MAP JULY 11, 1951, 1230 GMT

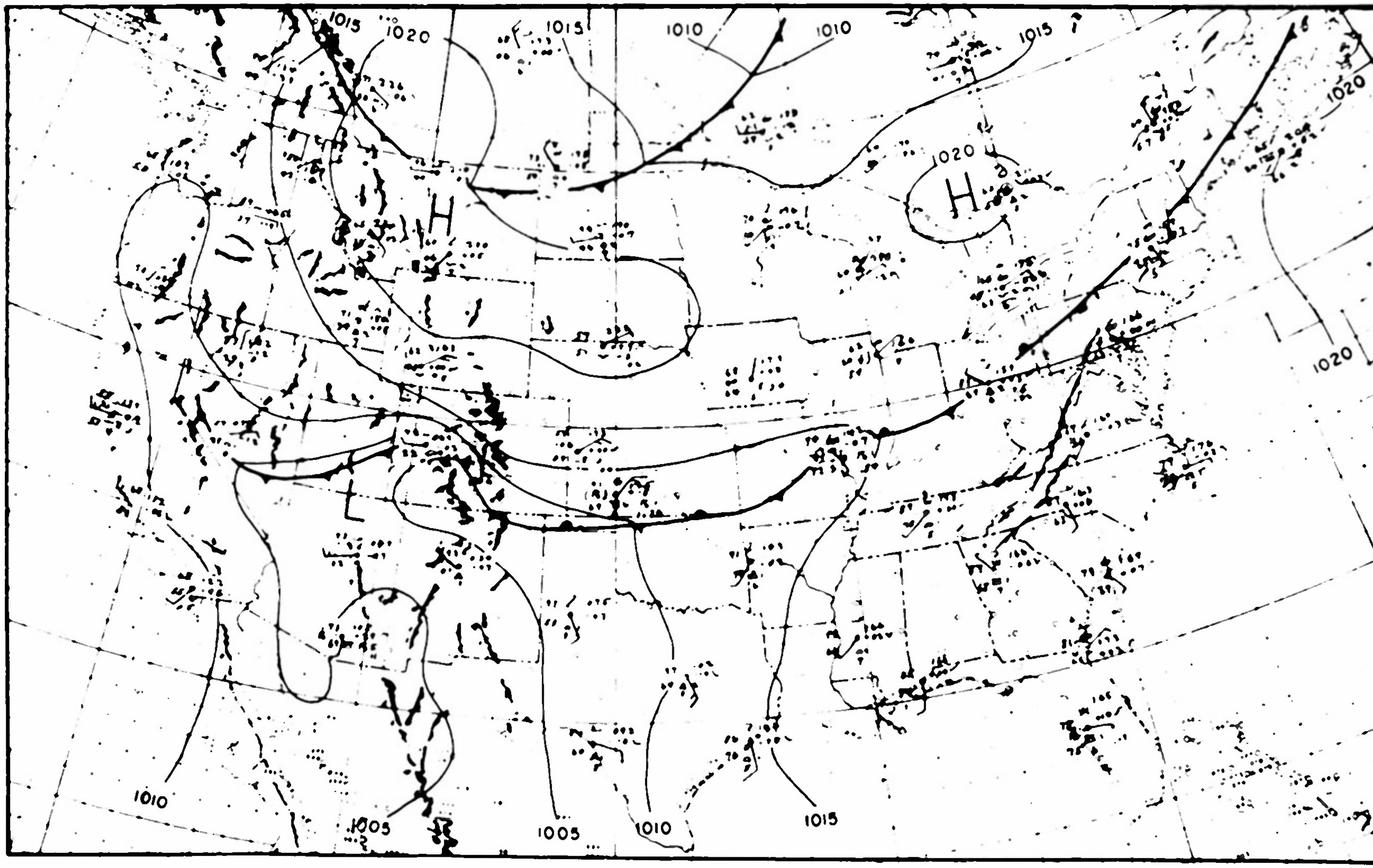


FIG. 9. SURFACE MAP JULY 12, 1951, 0030 GMT

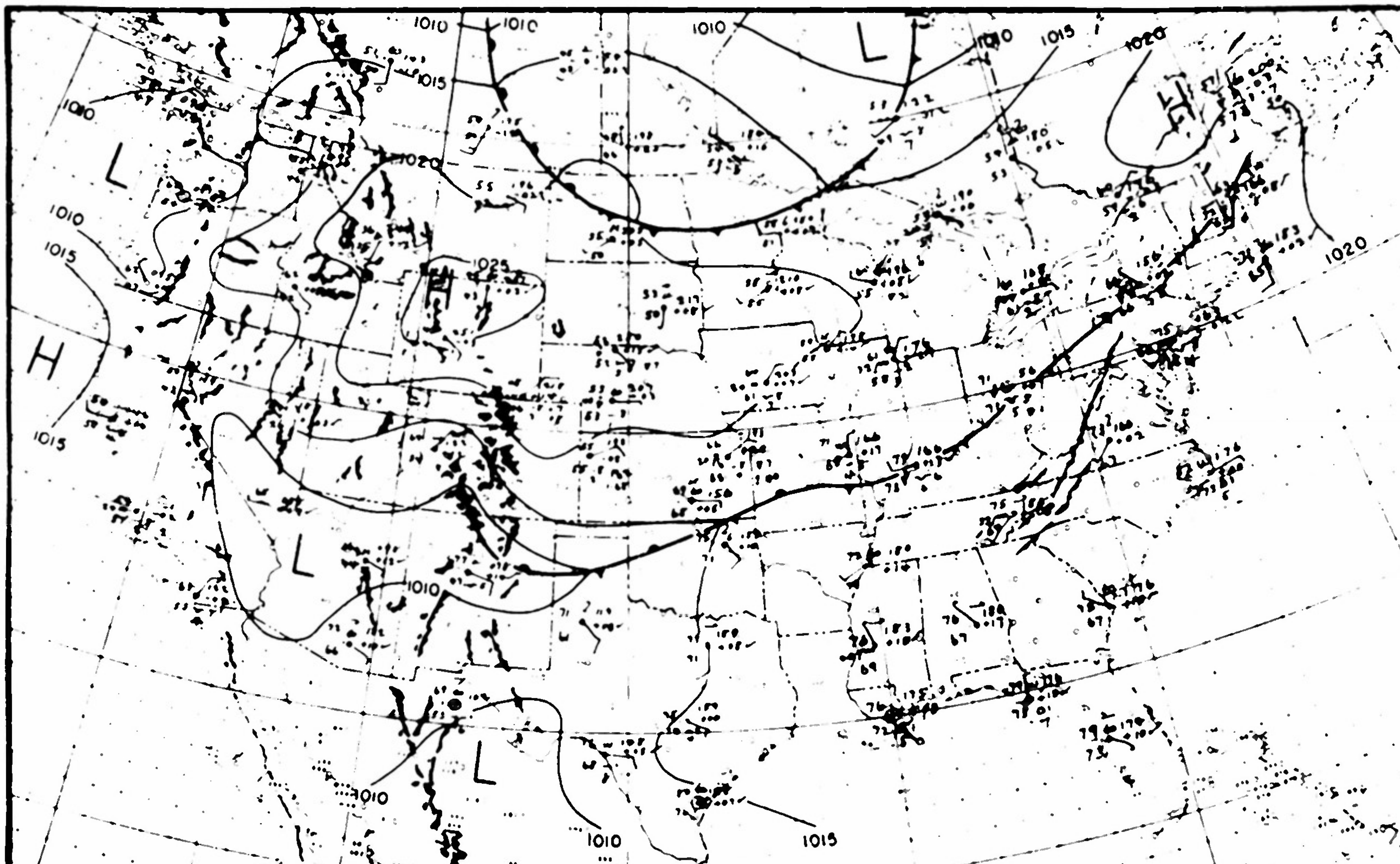


FIG. 10. SURFACE MAP JULY 12, 1951, 1230 GMT

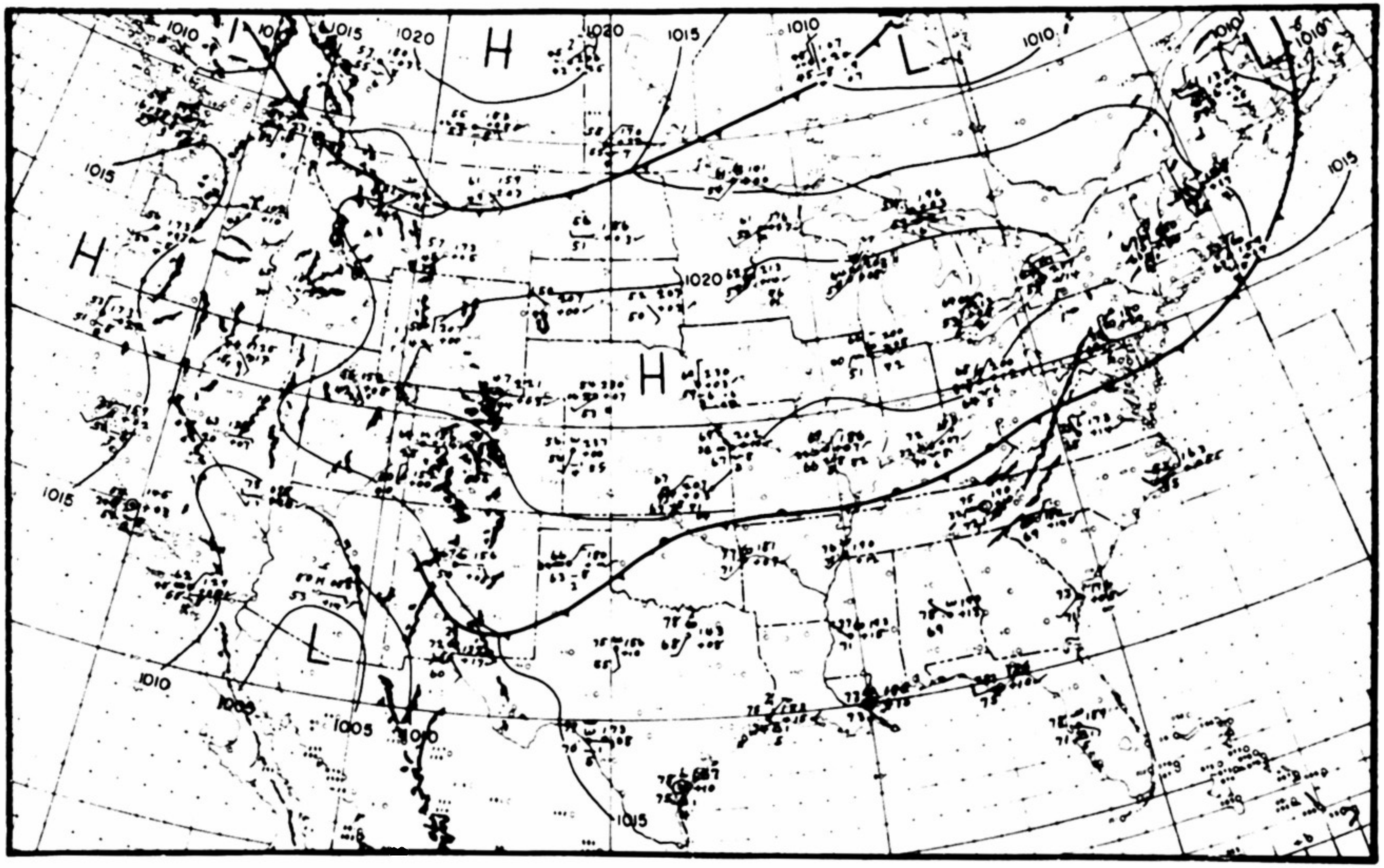


FIG. 11 SURFACE MAP JULY 13, 1951, 1230 GMT

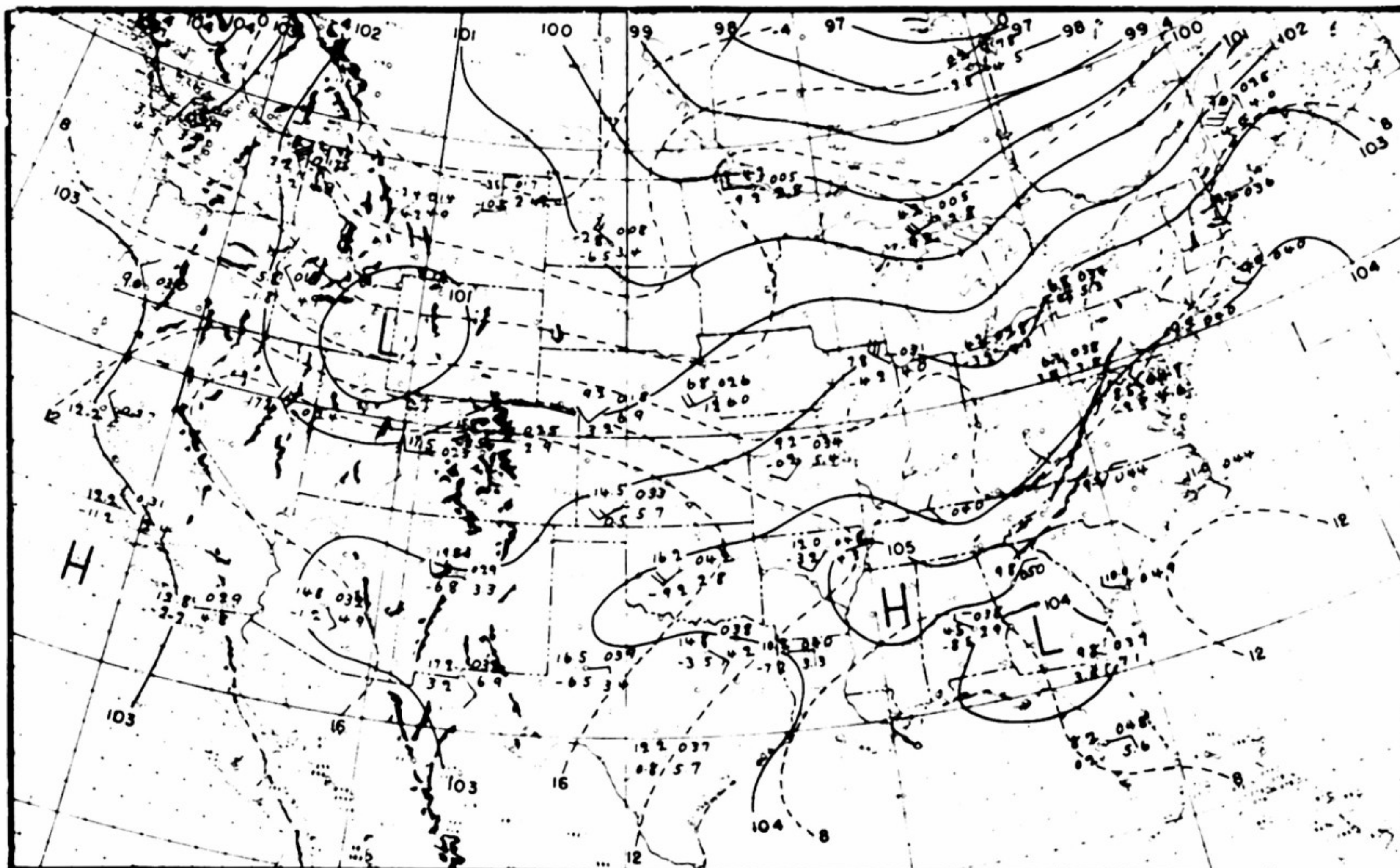


FIG. 12. 700-mb CHART JULY 10, 1951, 0300 GMT

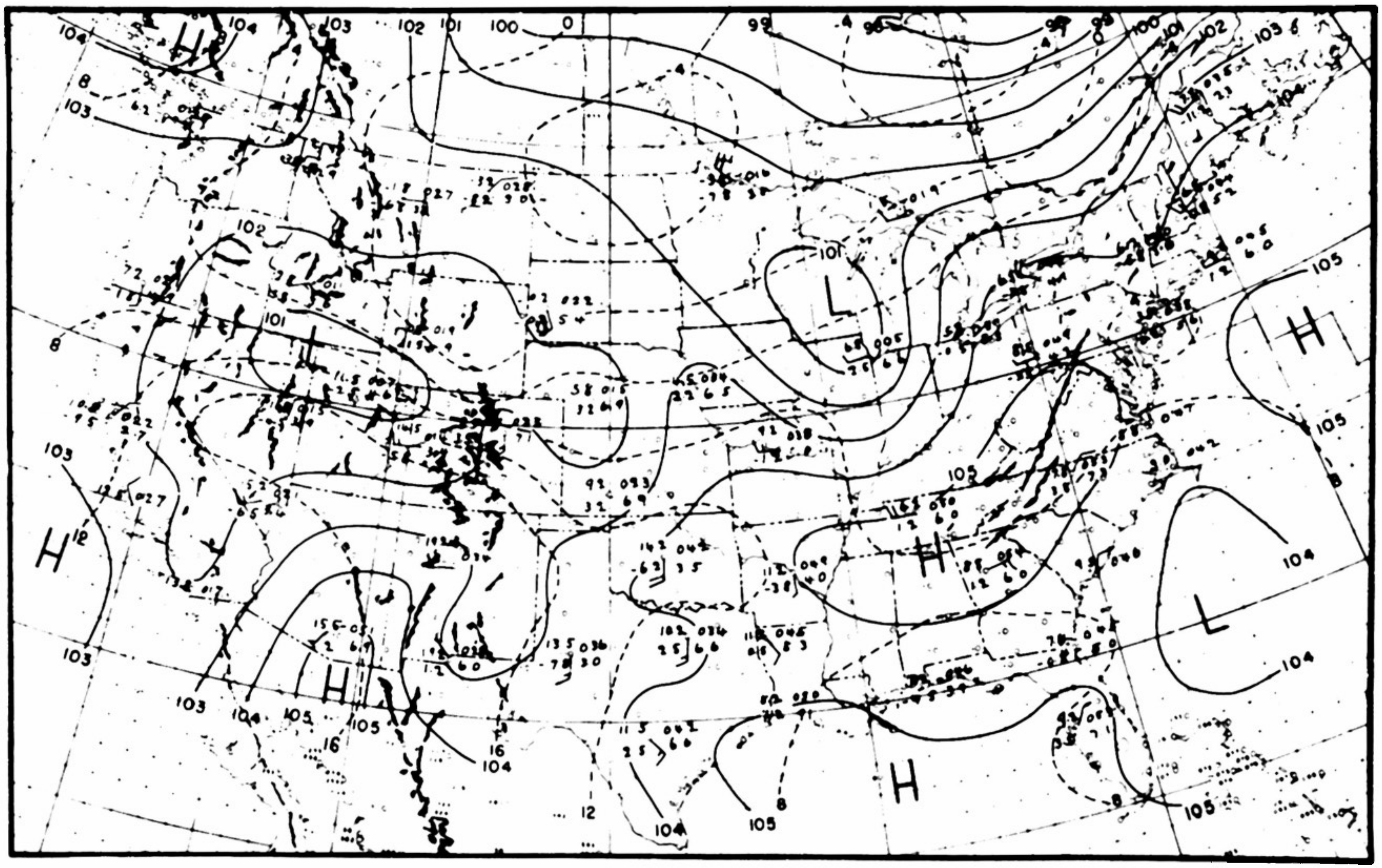


FIG. 13. 700-mb CHART JULY 11, 1951, 0300 GMT

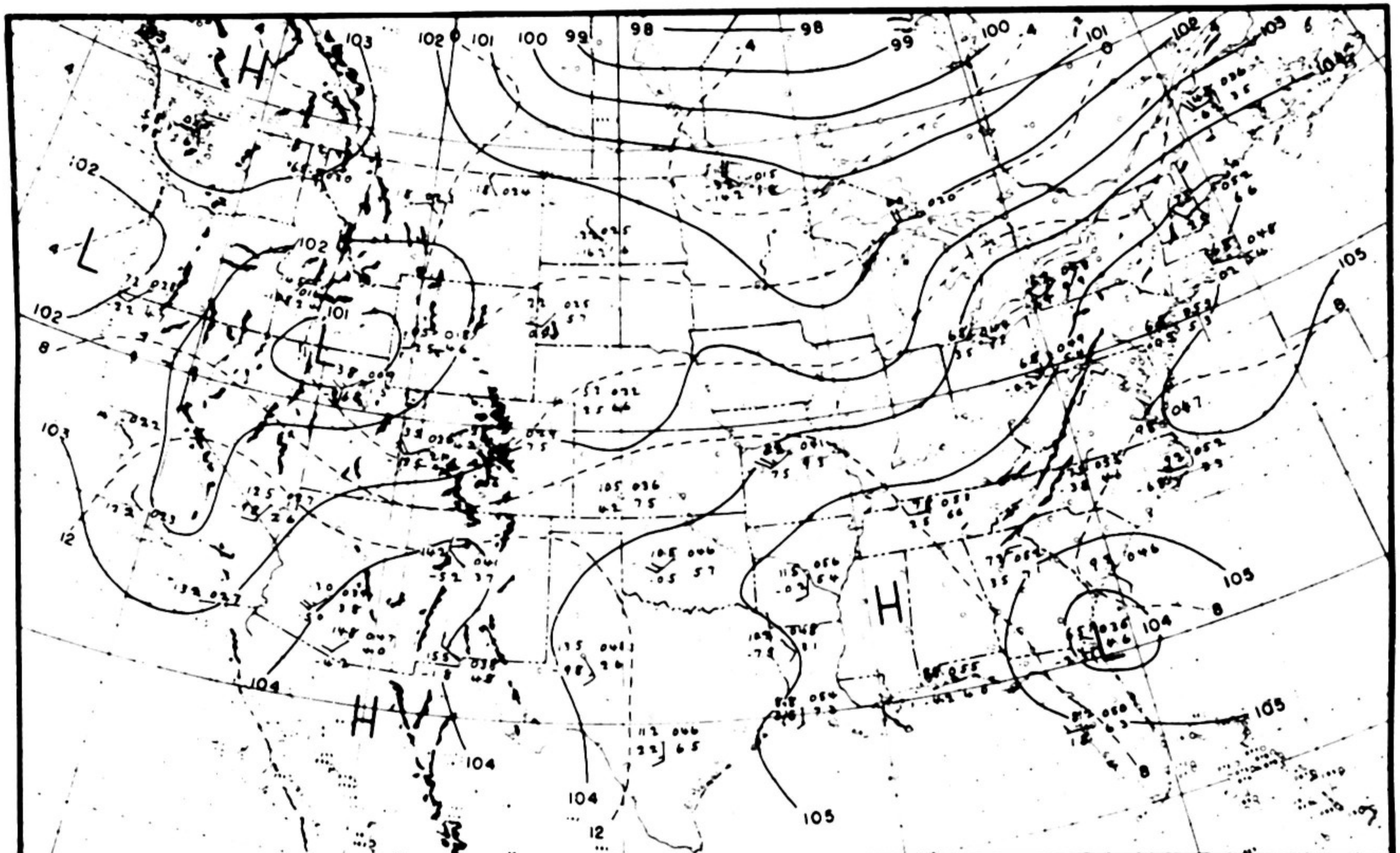


FIG. 14. 700-mb CHART JULY 11, 1951, 1500 GMT

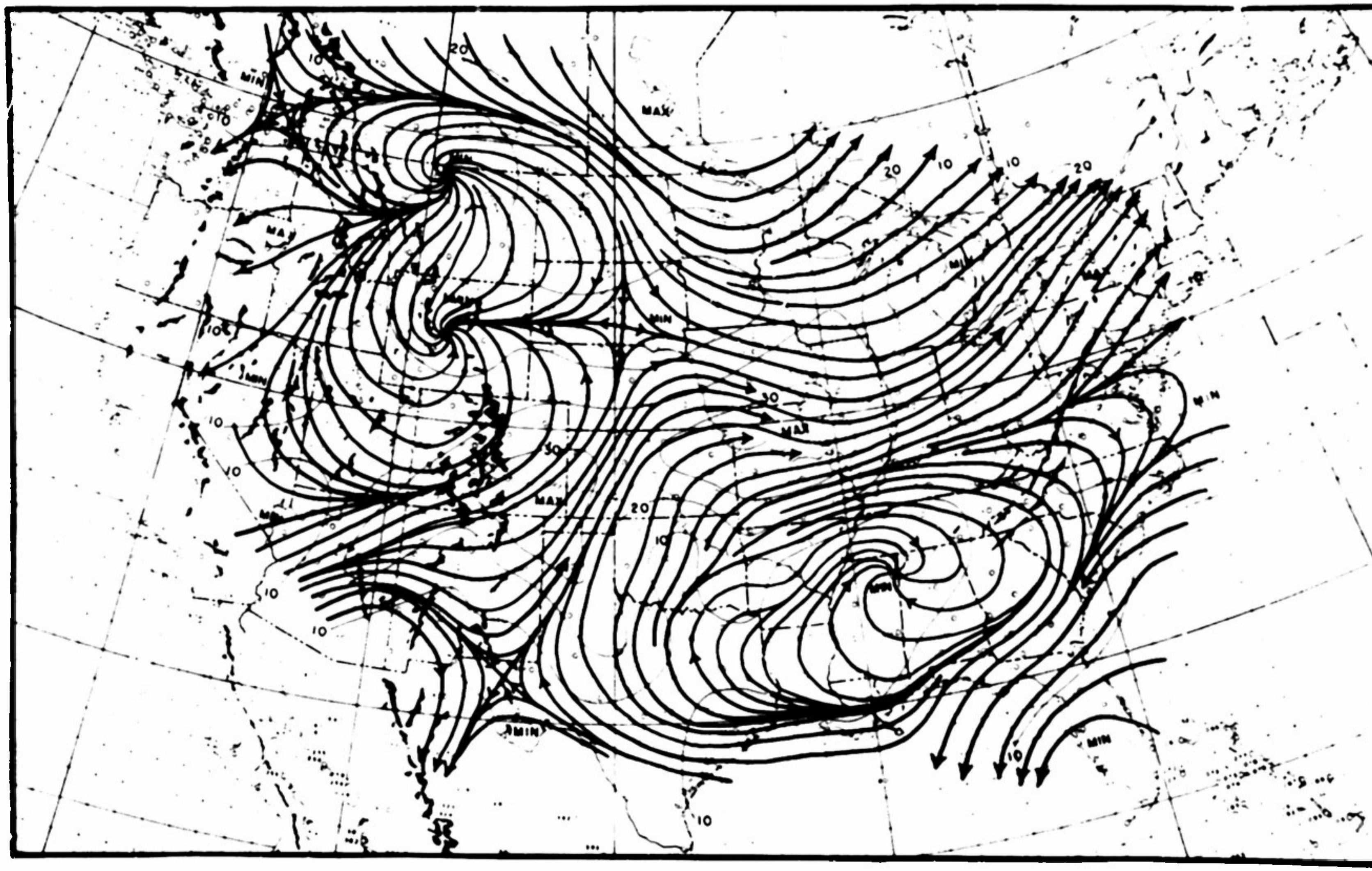


FIG. 15. 10,000-ft. STREAMLINE CHART JULY 12, 1951, 0300 GMT

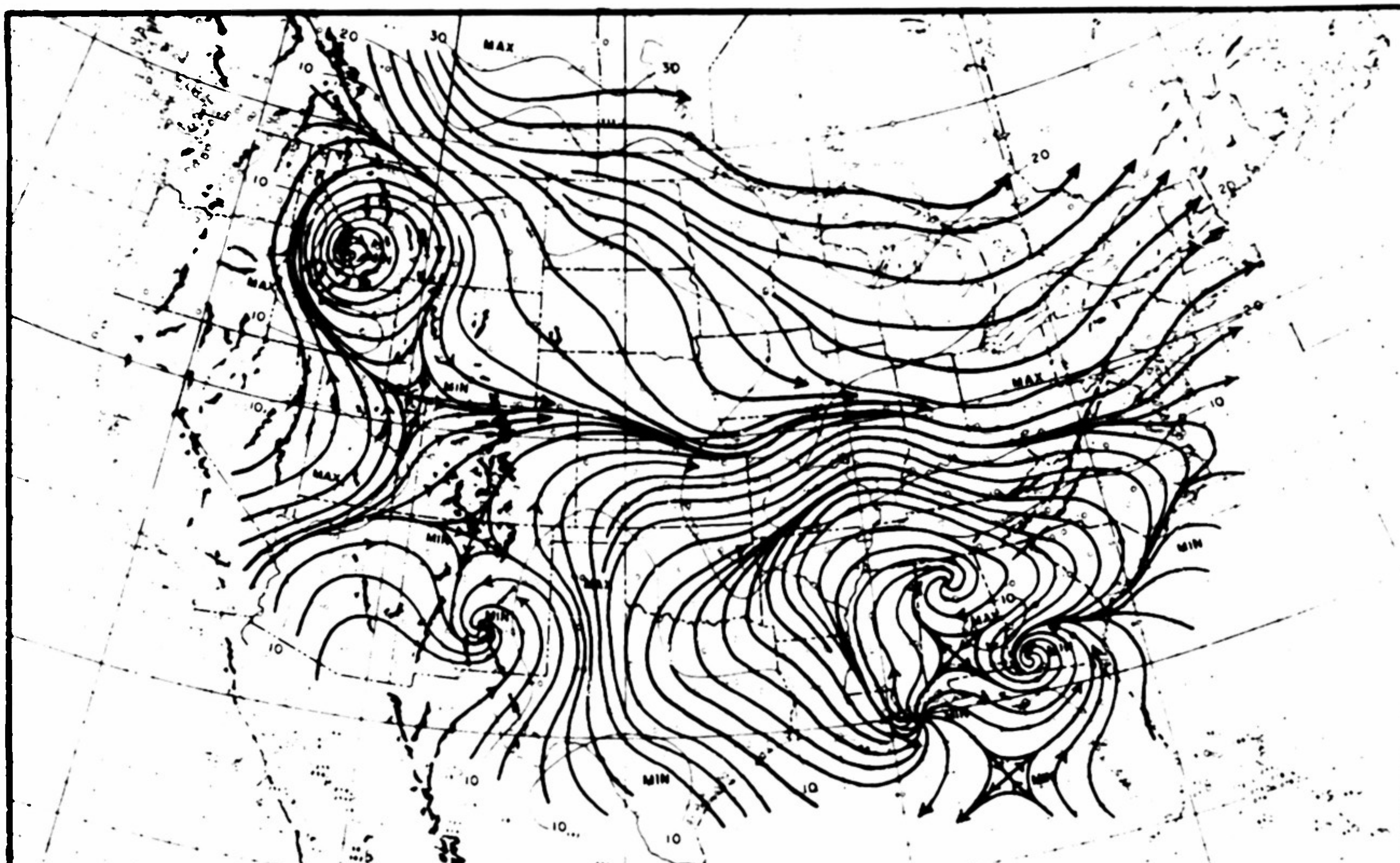


FIG. 16. 10,000 ft. STREAMLINE CHART JULY 12, 1951, 1500 GMT

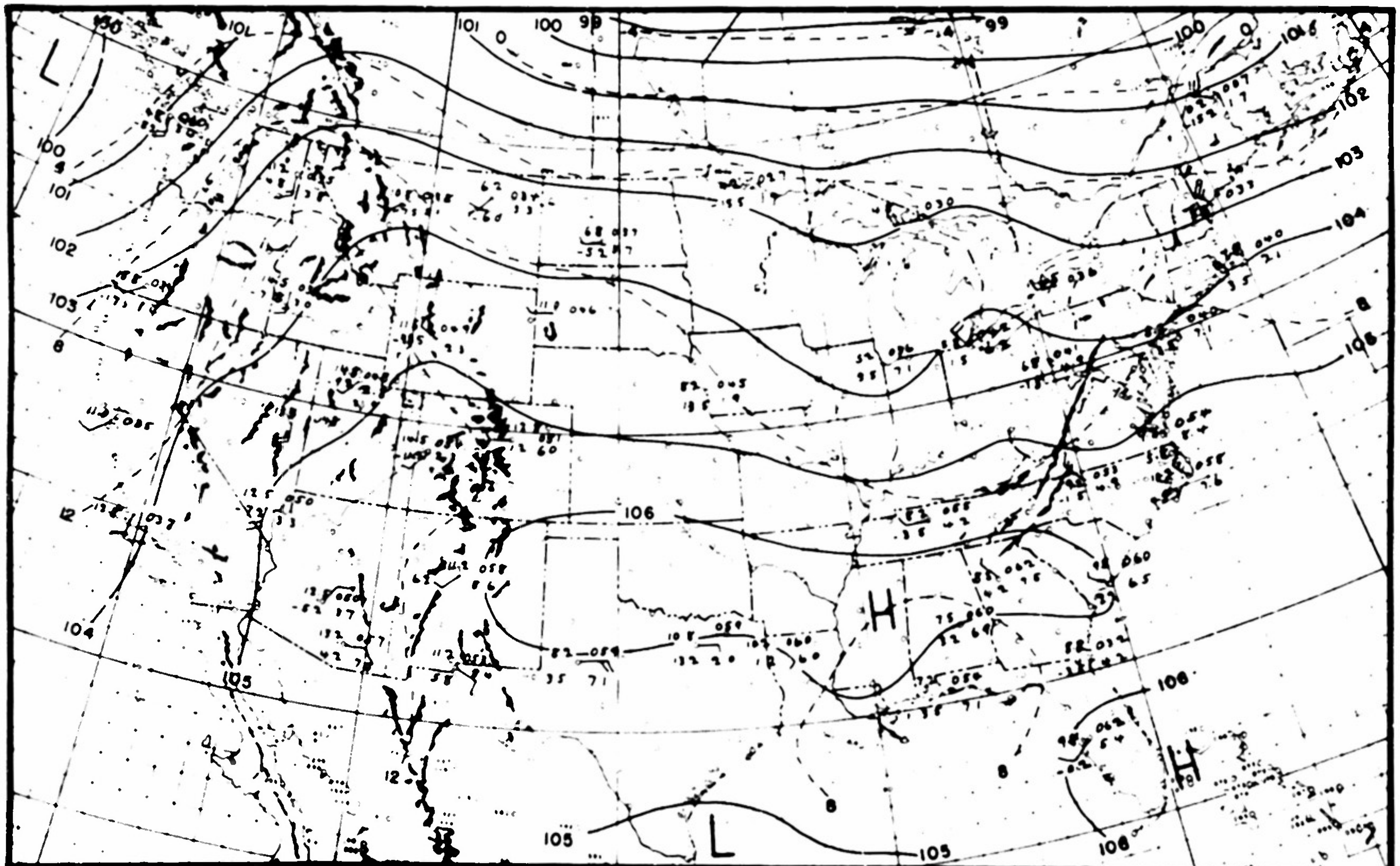


FIG. 17. 700-mb CHART JULY 13, 1951, 1500 GMT

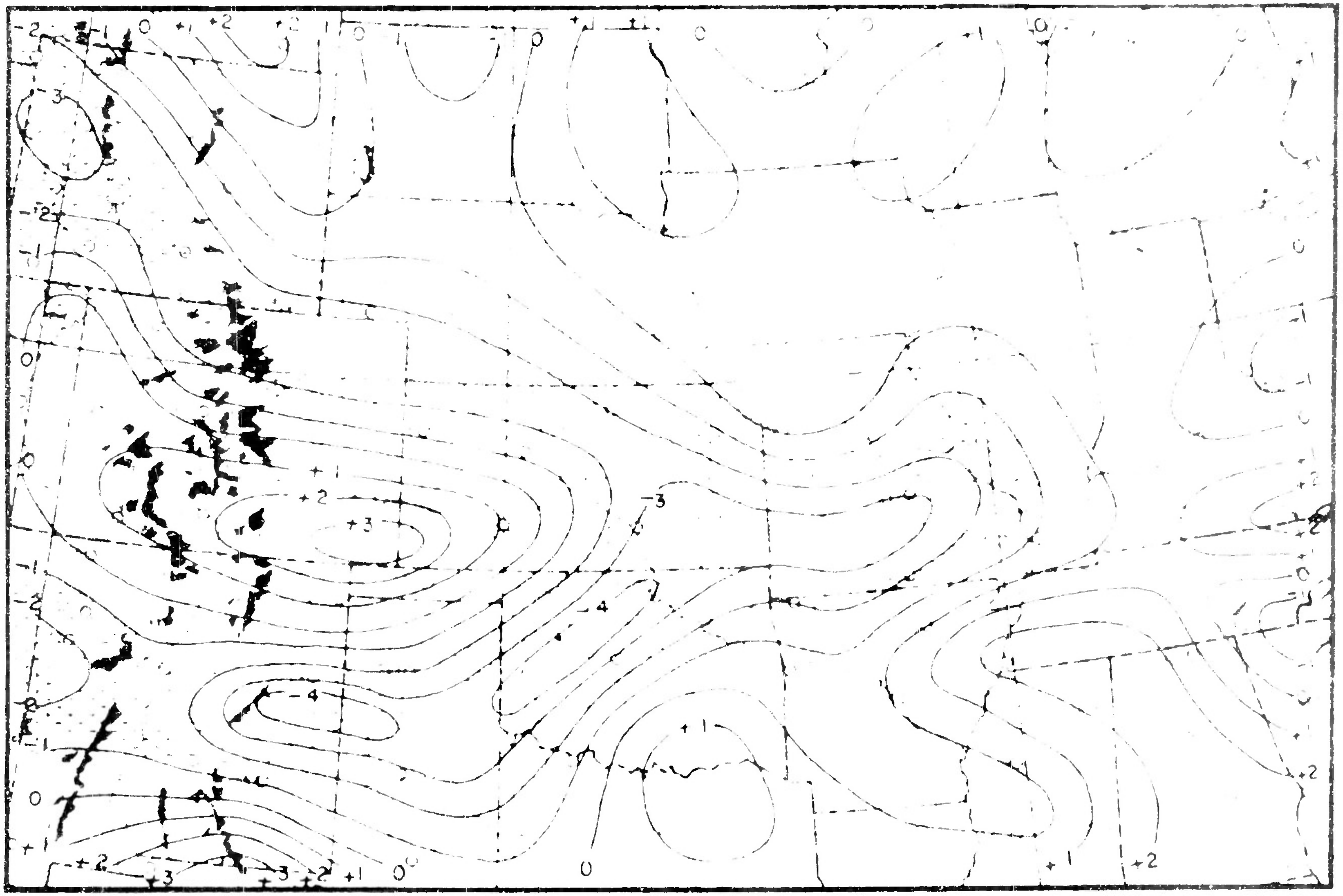


Fig. 18 10,000-ft Horizontal Velocity Divergence July 11, 1951, 0300 GMT (units of 10^{-5} sec^{-1})

Fig. 19 10,000-ft Horizontal Velocity Divergence July 11, 1951, 1500 GMT (units of 10^{-5} sec^{-1})

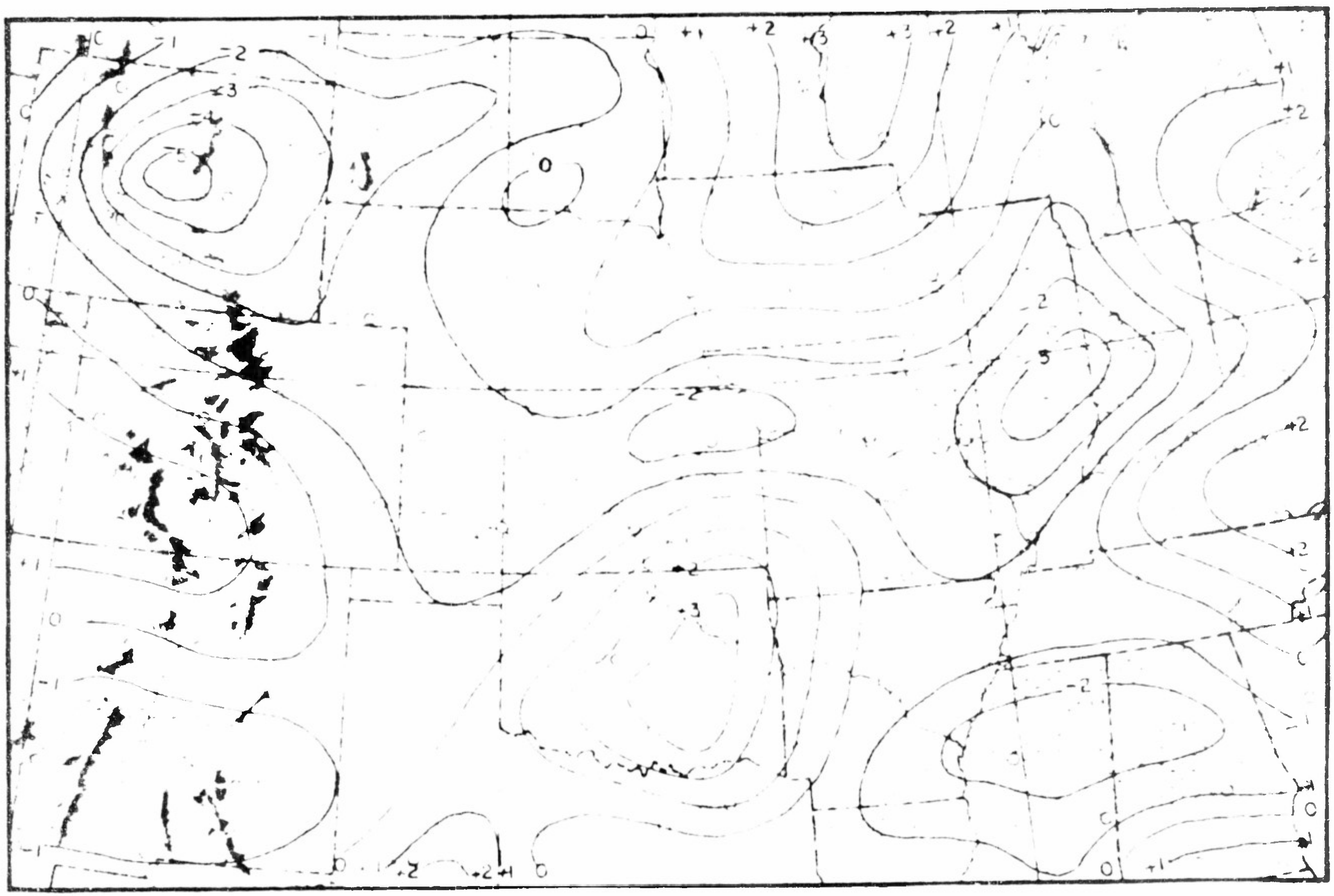


Fig. 20 10,000-ft Horizontal Velocity Divergence July 12, 1951, 0300 GMT (units of 10^{-5} sec^{-1})

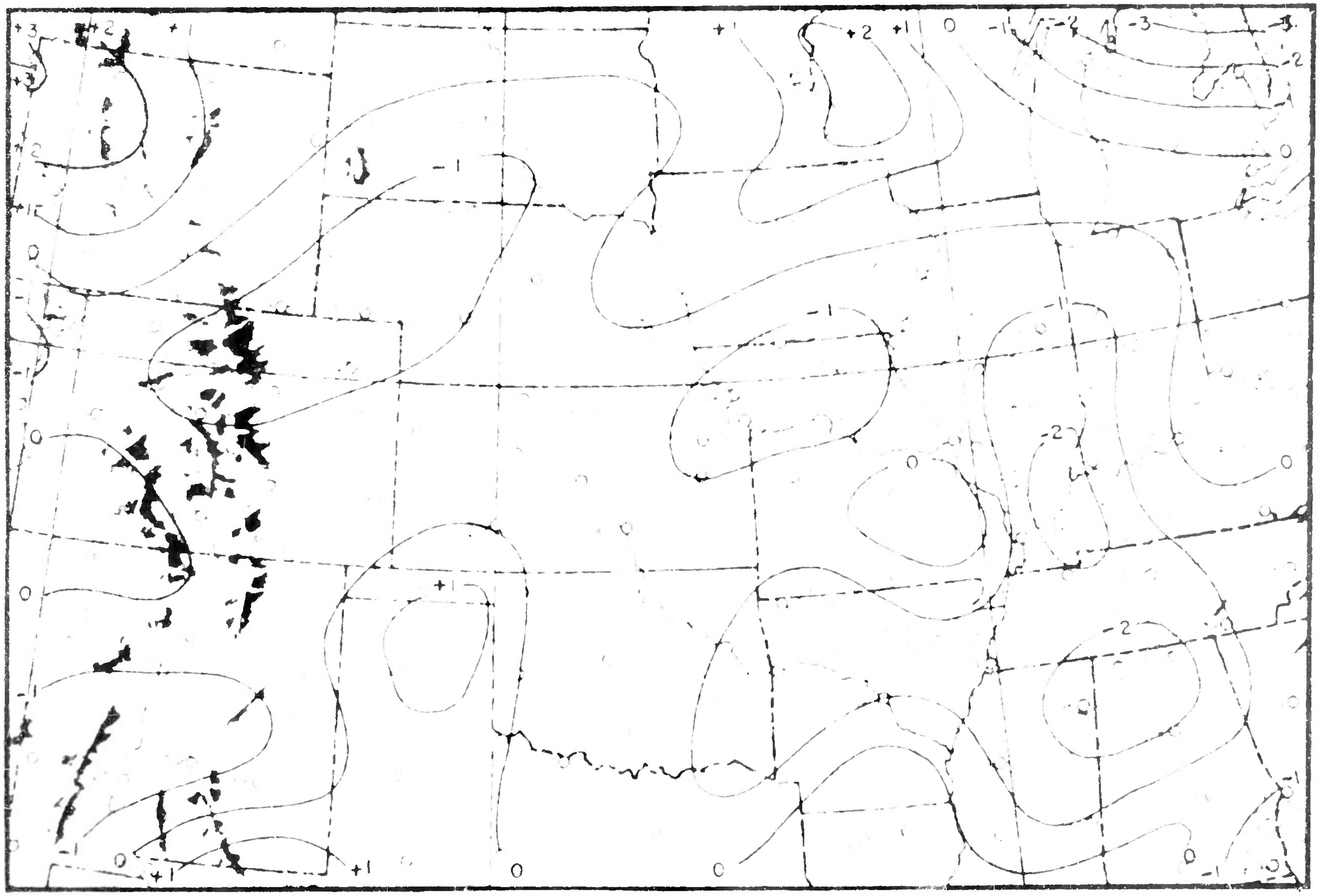
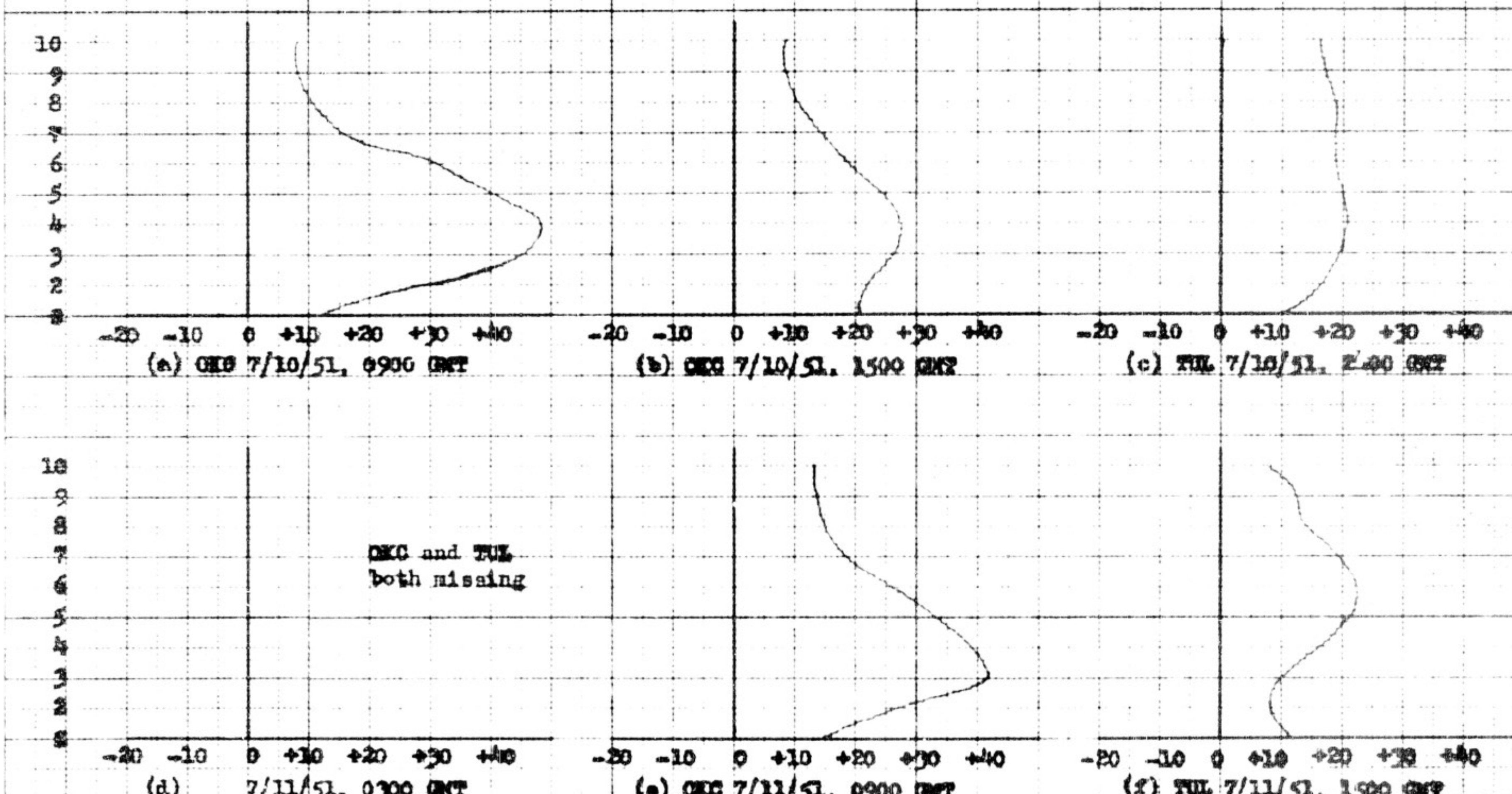


Fig. 21 10,000-ft Horizontal Velocity Divergence July 12, 1951, 1500 GMT (units of 10^{-5} sec^{-1})



Ordinate - Height in thousands of feet MSL
Abscissa - Northward component of wind in knots

OKC - Oklahoma City, Oklahoma, elevation 1,304 ft. MSL
TUL - Tulsa, Oklahoma, elevation 674 ft. MSL

Fig. 22. Profiles of the Northward Component of Wind at Oklahoma City or Tulsa July 10-13, 1951

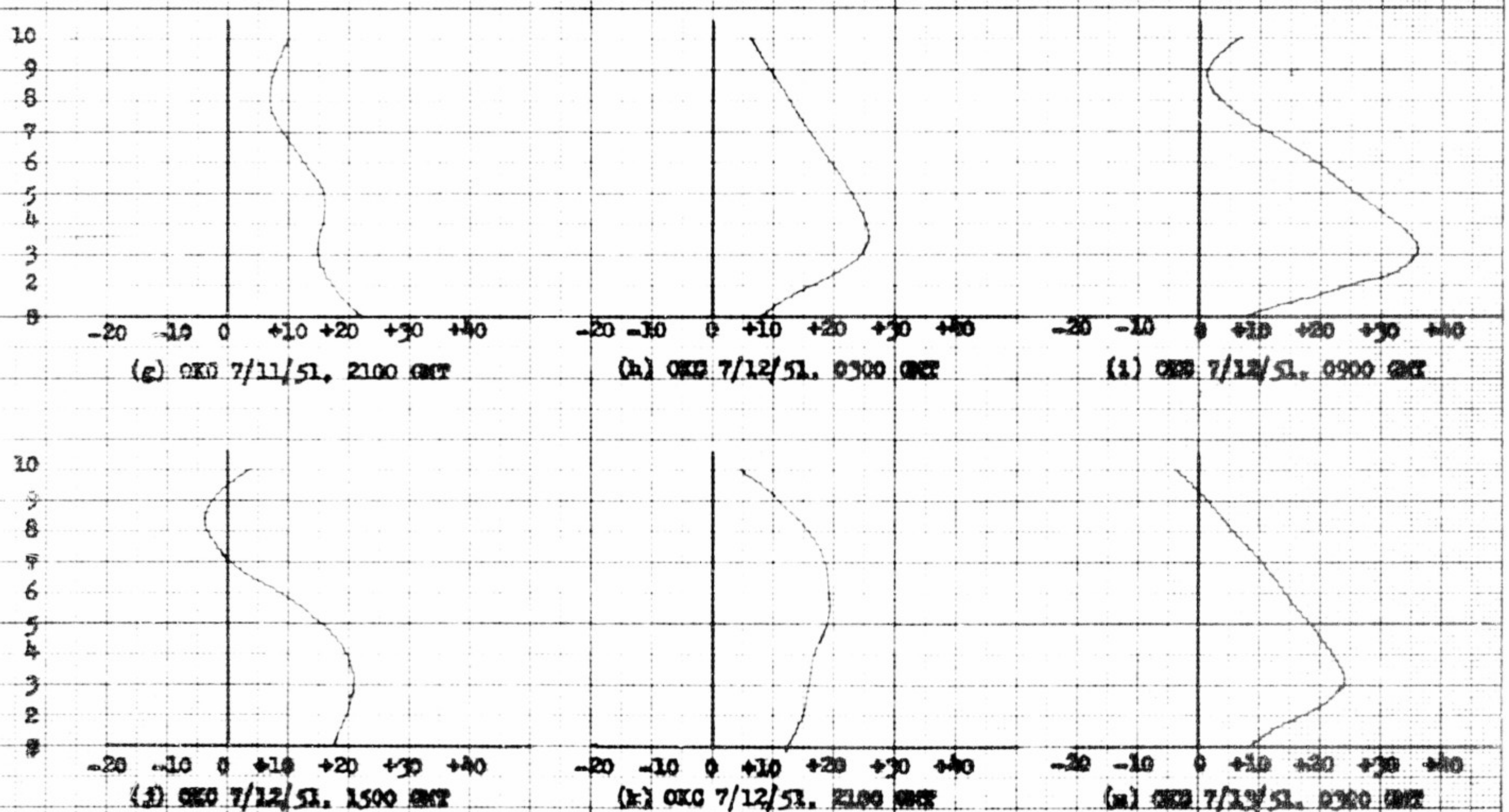

10
9
8
7
6
5
4
3
2
0
-20 -10 0 +10 +20 +30 +40
(g) OKC 7/11/51, 2100 GMT
(h) OKC 7/12/51, 0300 GMT
(i) OKC 7/12/51, 0900 GMT
(j) OKC 7/12/51, 1500 GMT
(k) OKC 7/12/51, 2100 GMT
(m) OKC 7/13/51, 0300 GMT

Fig. 22. (Cont'd)

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